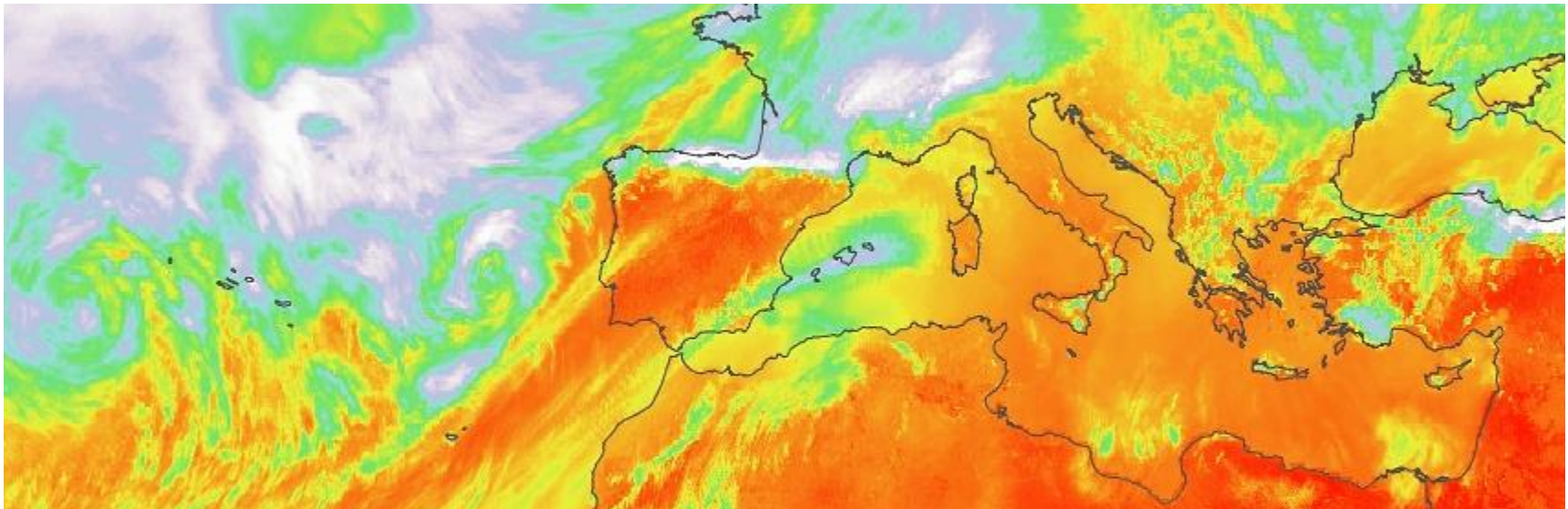


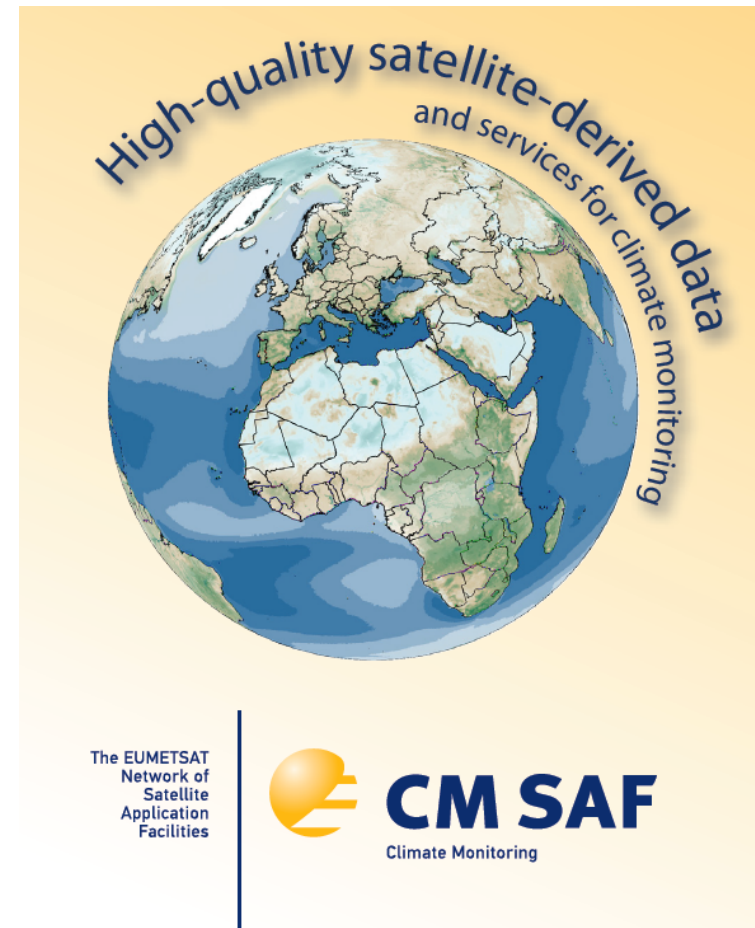
Trends and Variability of Surface Solar Radiation based on satellite-derived CM SAF Climate Data Records

Jörg Trentmann, Steffen Kothe, Richard Müller,
Uwe Pfeifroth, Arturo Sanchez-Lorenzo



*EUMETSAT Satellite Application Facility on
Climate Monitoring (www.cmsaf.eu)*

- Satellite-based climate data records of regional and global coverage
- Instruments: MVIRI-SEVIRI / GERB + AVHRR + SSM/I-SSMIS
- Surface and ToA radiation, cloud information, surface albedo, water vapor, ocean surface fluxes + precipitation
- Data available: Jan 1982 to October 2016
- Resolutions from 0.03° to 1° and from 15 min to monthly means
- Data freely available: www.cmsaf.eu/wui



Surface Solar Radiation Dataset – Heliosat (SARAH)

→ Variables

- Global irradiance (SIS)
- Direct (normalized) irradiance (SID, DNI)
- Effective cloud albedo (CAL)

→ Resolution

- Spatial: $0.05^\circ \times 0.05^\circ$
- Temporal: hourly, daily, monthly means

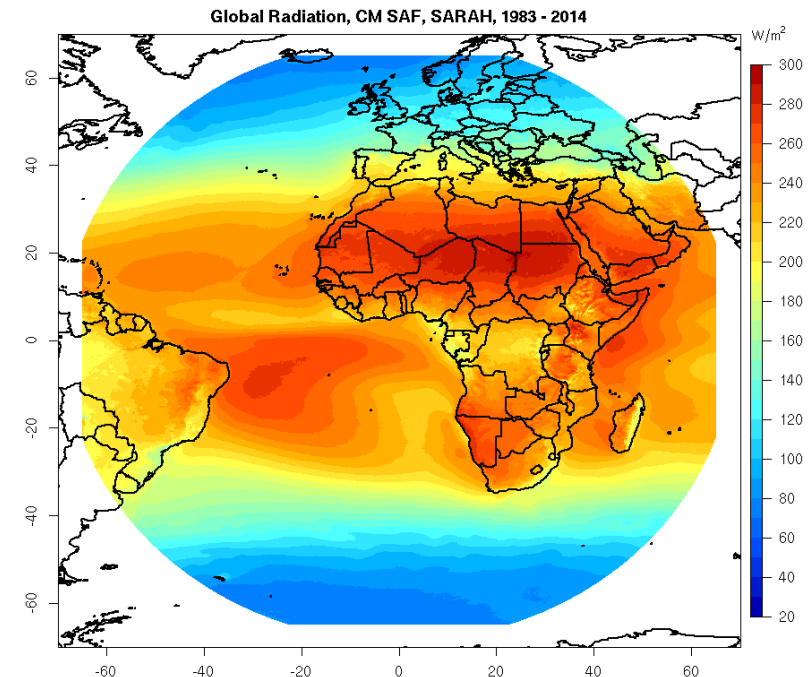
→ Coverage

- Spatial: Meteosat-Prime Full disk
- Temporal: 1983 to 2015

→ Satellites / Instruments

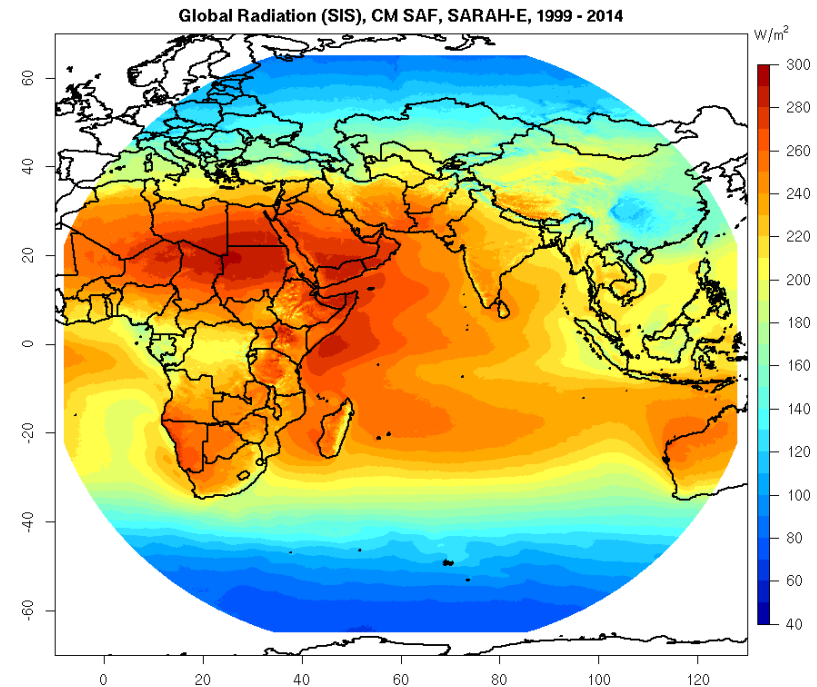
- Meteosat 2 to 10 (MVIRI/SEVIRI)

→ ‘Heliosat’-retrieval method



Surface Solar Radiation Dataset – Heliosat (SARAH-E)

- **Variables**
 - Global irradiance (SIS)
 - Direct (normalized) irradiance (SID, DNI)
- **Resolution**
 - Spatial: $0.05^\circ \times 0.05^\circ$
 - Temporal: hourly, daily, monthly means
- **Coverage**
 - Spatial: Meteosat-Prime ~~IODC~~ Full disk
 - Temporal: ~~1983~~ **1999** to 2015
- **Satellites / Instruments**
 - Meteosat 2 to 10 **5 and 7** (MVIRI/SEVIRI)
- 'Heliosat'-retrieval method



CLARA (Clouds, Albedo, Radiation based on AVHRR)

→ Variables

- Global irradiance (SIS)
- Up- and downwelling longwave (SDL, SOL)

→ Resolution

- Spatial: $0.25^\circ \times 0.25^\circ$
- Temporal: daily, monthly means

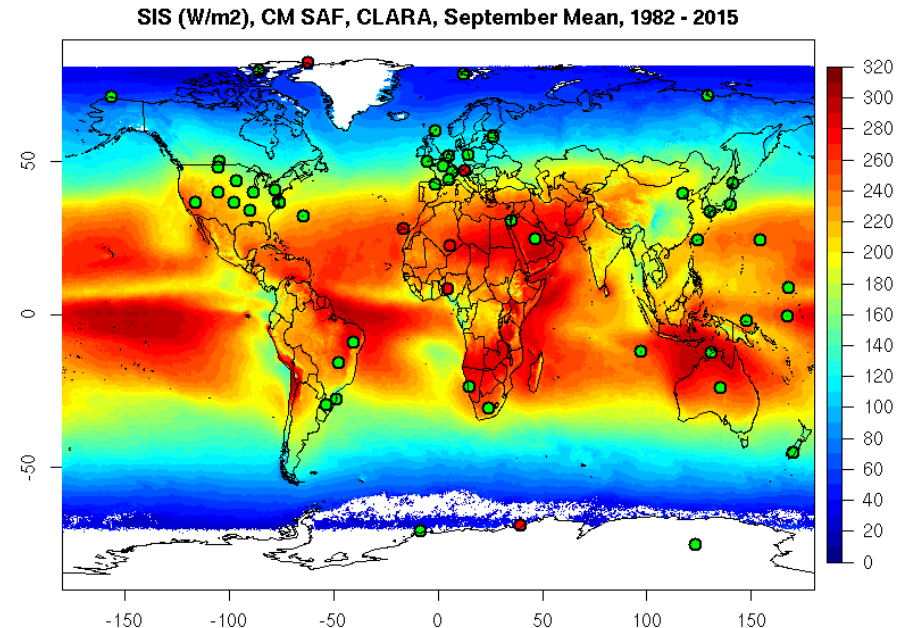
→ Coverage

- Spatial: Global
- Temporal: 1982 to 2015

→ Satellites / Instruments

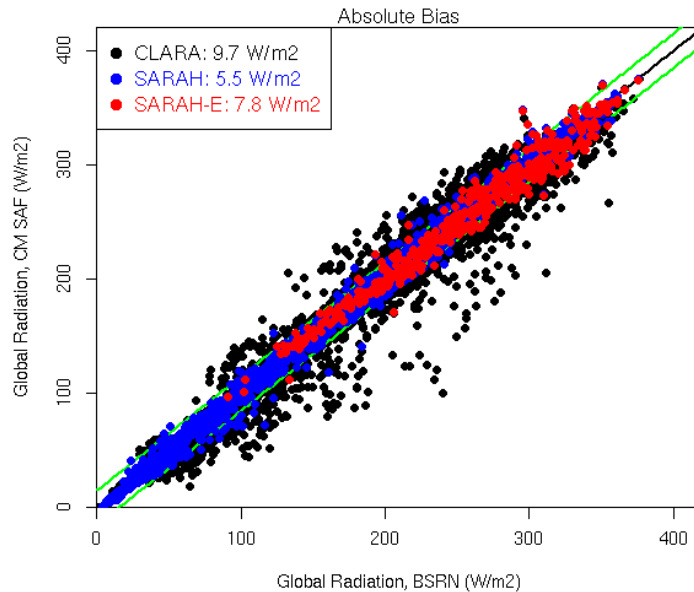
- NOAA / Metop (AVHRR)

→ 'Pinker-Laszlo'-look-up-table retrieval method

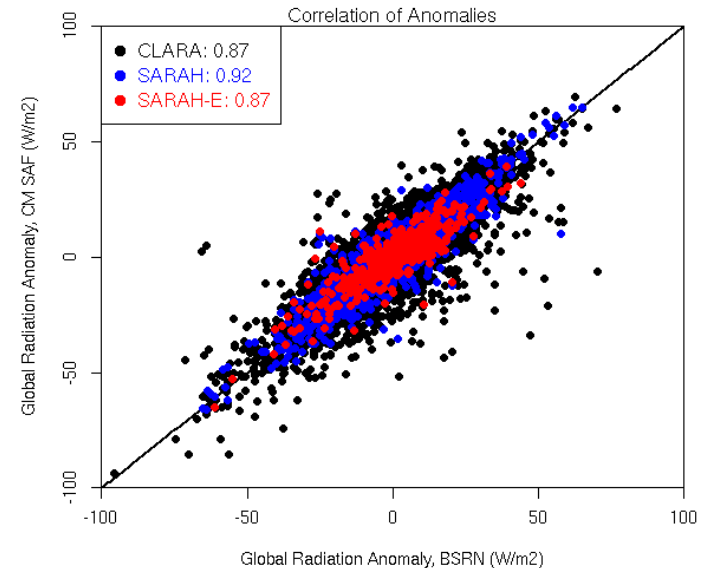


Quality assessment by comparison with BSRN

Accuracy



Suitability for Climate Monitoring

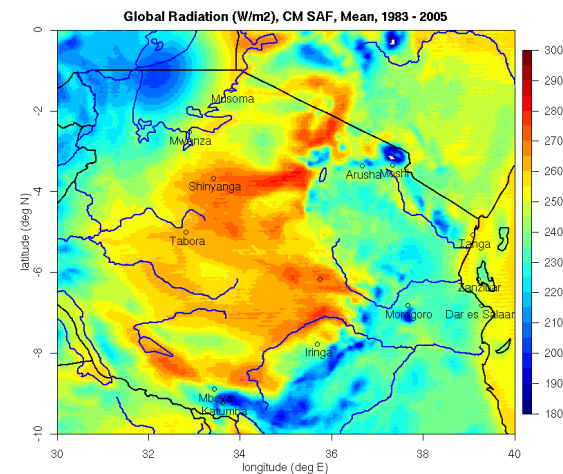
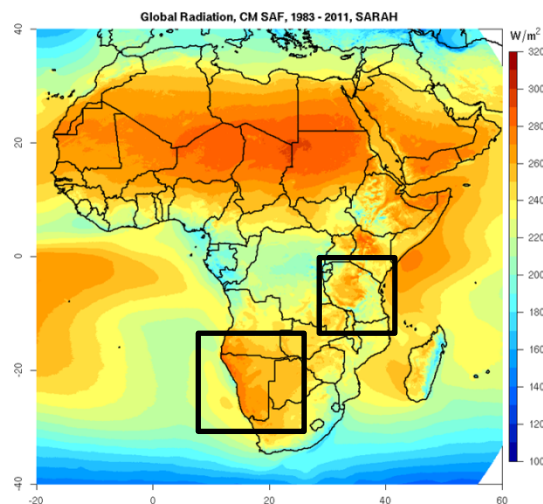
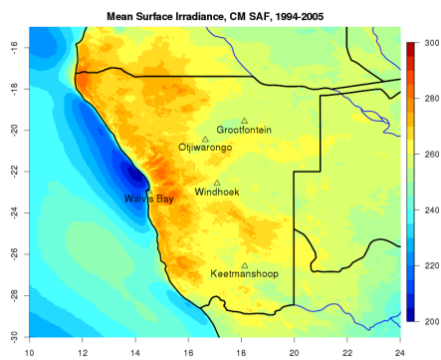
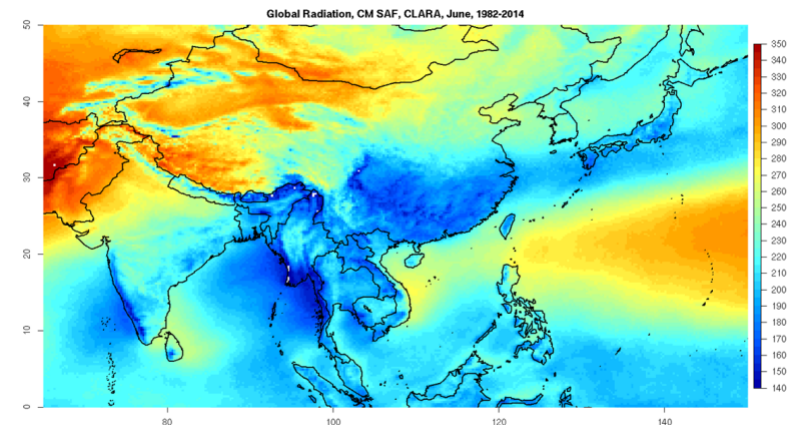
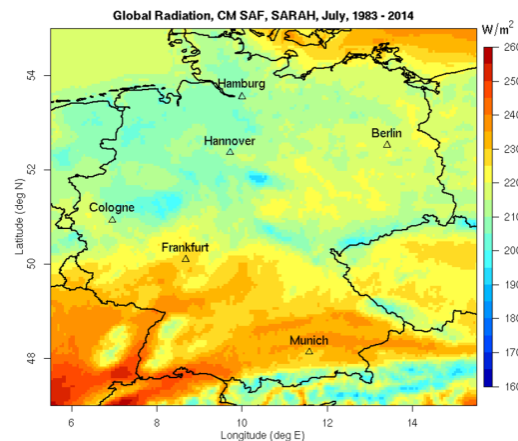
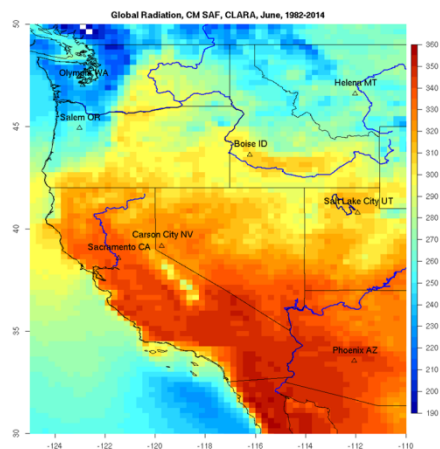


Quality assessment by comparison with BSRN

Data	N _{obs}	Bias [W/m ²]	MAB [W/m ²]	AC
SARAH 1983 – 2015, 0.05°	1902 <i>56.111</i>	0.8 <i>0.7</i>	5.5 <i>11.9</i>	0.92 <i>0.95</i>
SARAH-E 1999 – 2015, 0.05°	474 <i>13.717</i>	-1.6 <i>-1.7</i>	7.8 <i>15.0</i>	0.87 <i>0.90</i>
CLARA 1982 – 2015, 0.25°	6433 <i>181.713</i>	-2.4 <i>-2.6</i>	9.7 <i>19.5</i>	0.87 <i>0.89</i>
CERES SYN1deg 2000 – 2015, 1.0°	5392 <i>153.479</i>	2.4 <i>2.3</i>	8.2 <i>17.5</i>	0.88 <i>0.91</i>

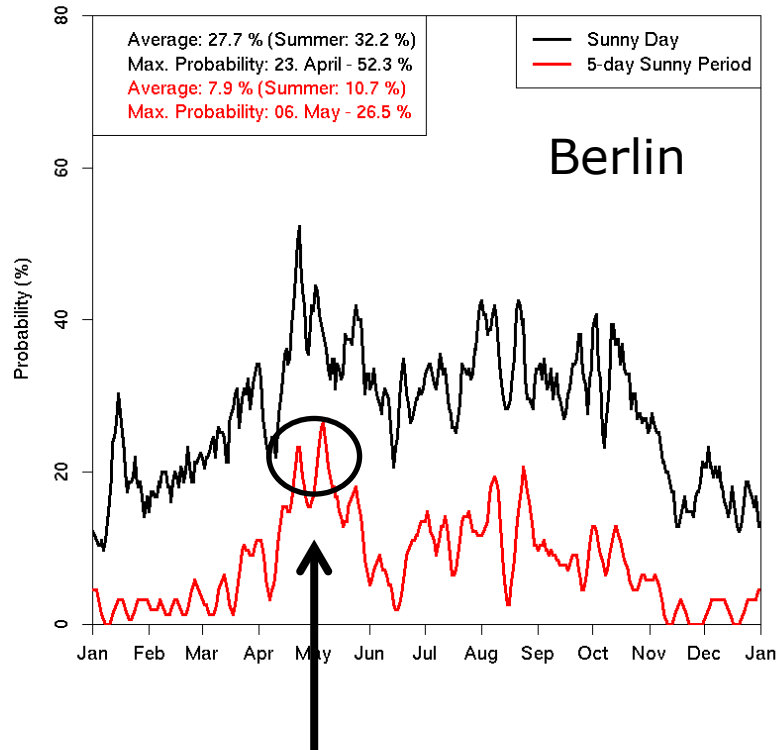
- Surface Irradiance from CM SAF Climate Data Records is very accurate
- Compared to CERES: extended temporal coverage, higher spatial resolution

Solar Radiation Climatology



Sunny Days

Probability of Sunny Days / Periods, Berlin



Highest likelihood of stable, sunny conditions beg. May

Sunny Day: Global radiation larger than 80 % of the clear-sky radiation



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www.cmsaf.eu/SunnyDays

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- new service message No 91 (March)
- updated Change Log \ Climate Data Set
- updated Digital Object Identifier
- new service message No 90 (Feb)
- > More

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Probability of sunny days for selected stations based on CM SAF data

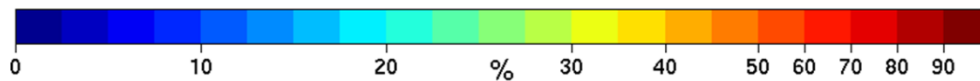
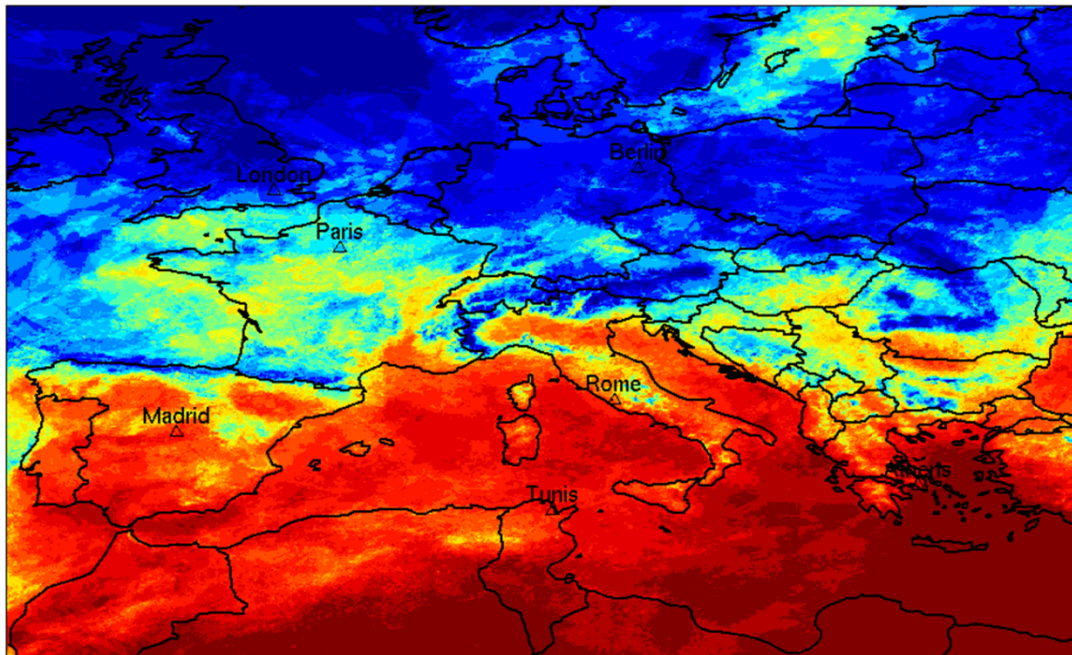
The annual cycle of the probability of sunny days is shown for selected European cities (click on the marker next to the city to open a small version of the figure. This figure can be enlarged by clicking on the figure). For the selected city the likelihood that a certain day throughout the year is sunny (black line) or within a 5-day sunny period (red line) is shown. The date with the highest probability for a sunny day / sunny period is also given. For most cities certain periods with higher / lower probabilities of a sunny day can be identified. Due to the climatological basis of this analysis, individual years will be different to the annual cycles shown here.



Globally available for many cities!

Where to go in mid June?

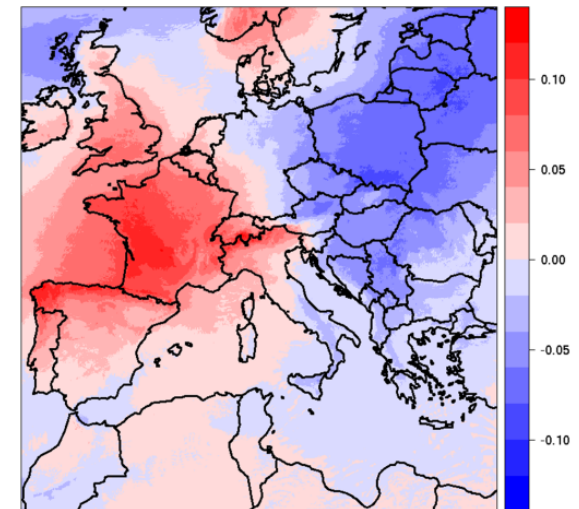
18 June: Probability 5-day Sunny Period



Mid June:

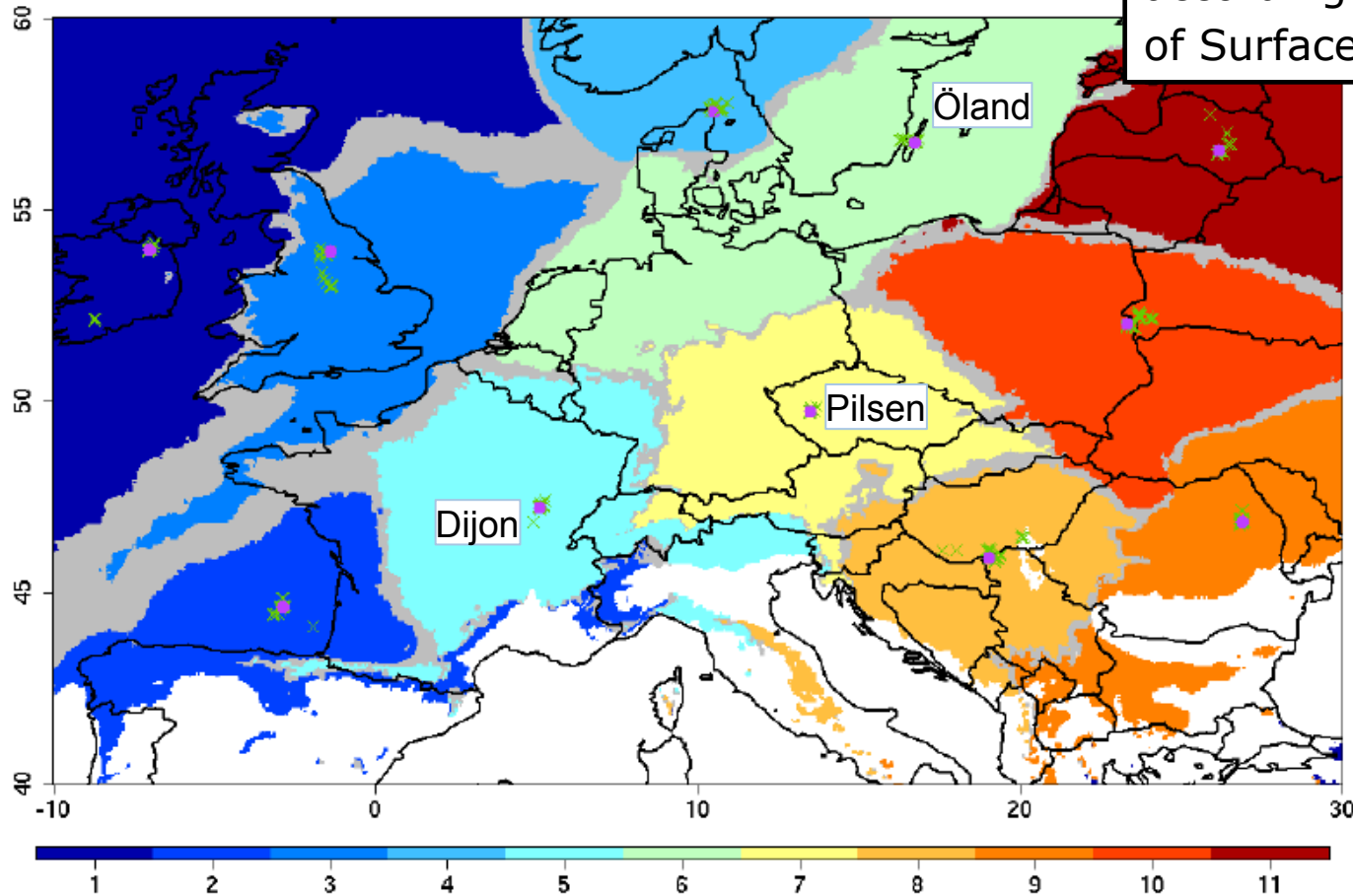
- High probability of sunshine in France / low probability in North-Eastern Europe
- corresponding weather situations more frequent

Mean Anomaly of the Clear Sky Index, GWL: 1, 2, 7, 10, 12, 19

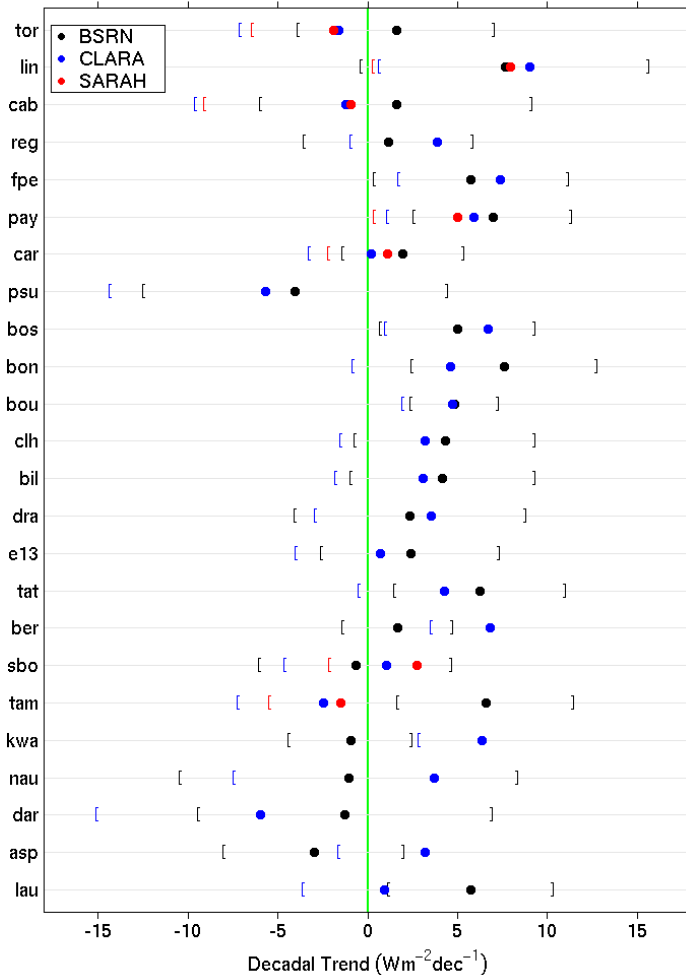


Cluster Analysis of daily irradiance

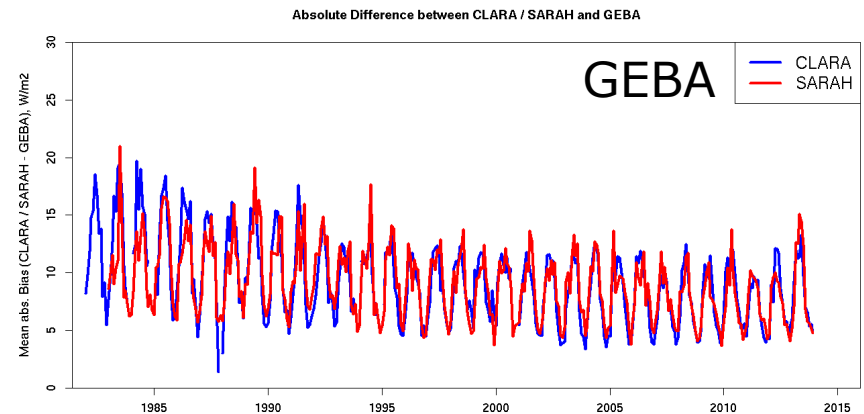
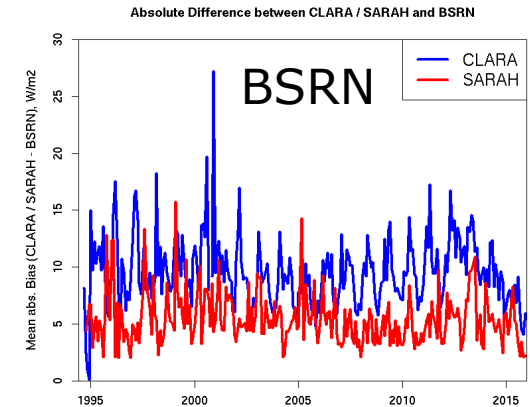
Grouping European Regions according to their variability of Surface Radiation



Assessment of temporal stability and trends



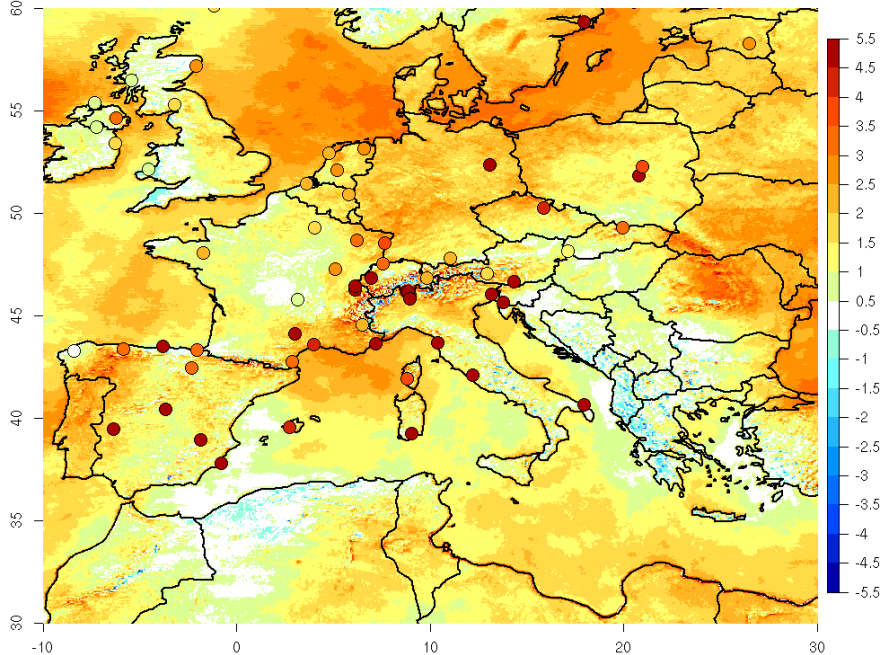
- Accuracy of data records stable compared to BSRN and GEBA
- Temporal trends from BSRN are reproduced.



Trends in Europe

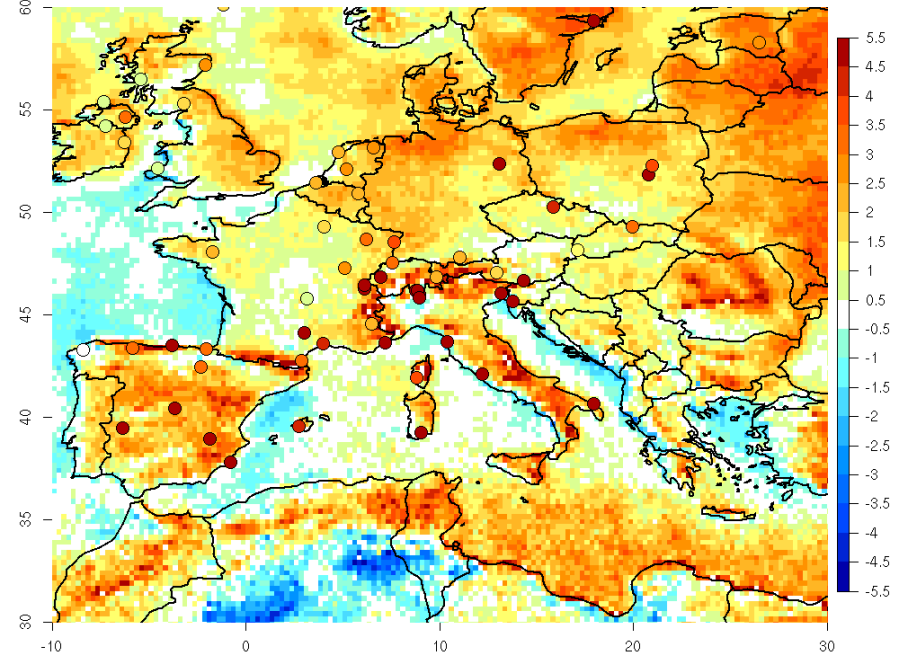
Trend in Surface Irradiance, Europe, SARAH, 1983 - 2014

SARAH



Trend in Surface Irradiance, Europe, CLARA, 1982 - 2014

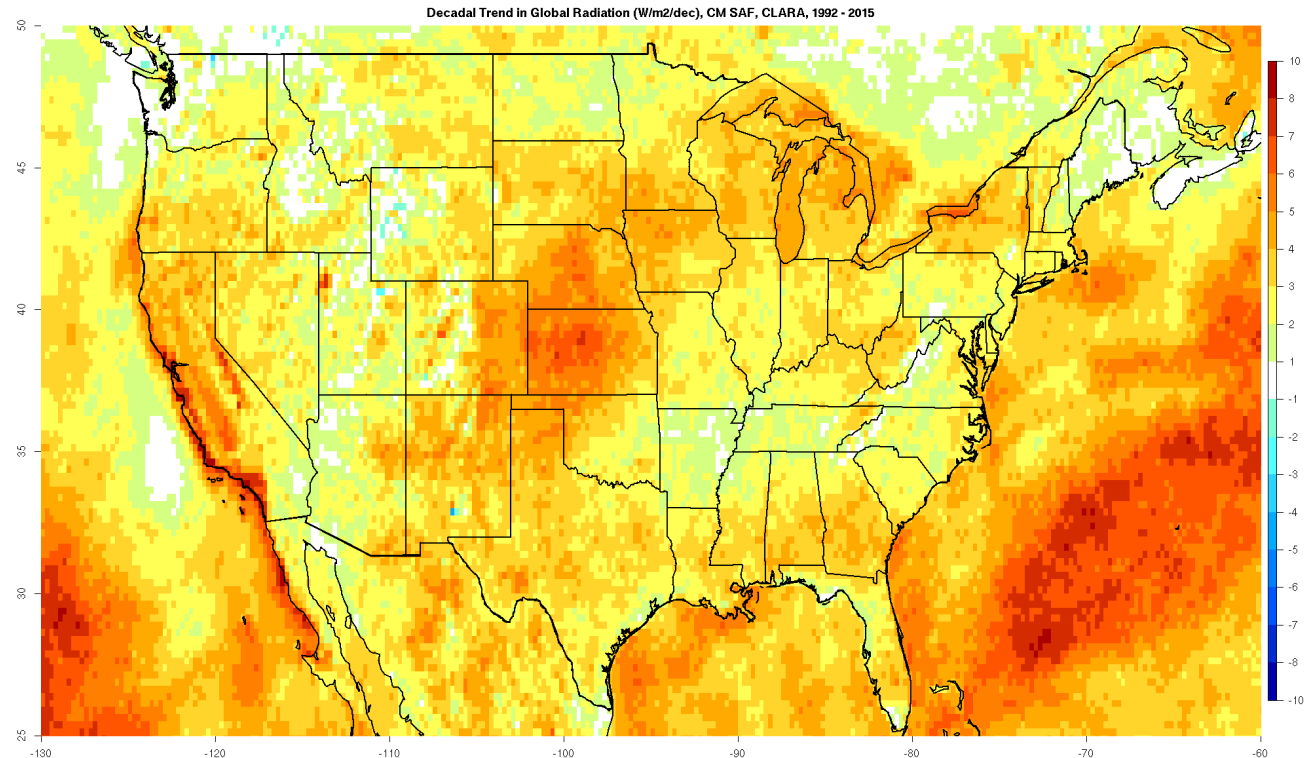
CLARA



- Positive trend of surface irradiance in satellite data records; both data records show consistent patterns
- Substantial spatial variability of the trend (consistent with GEBA)

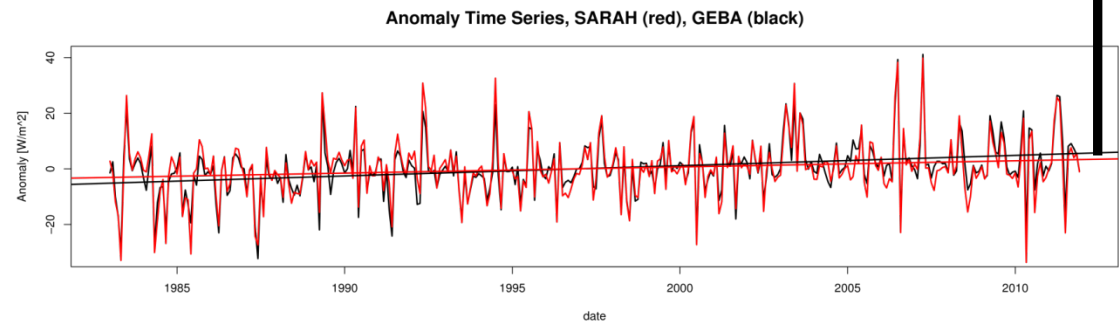
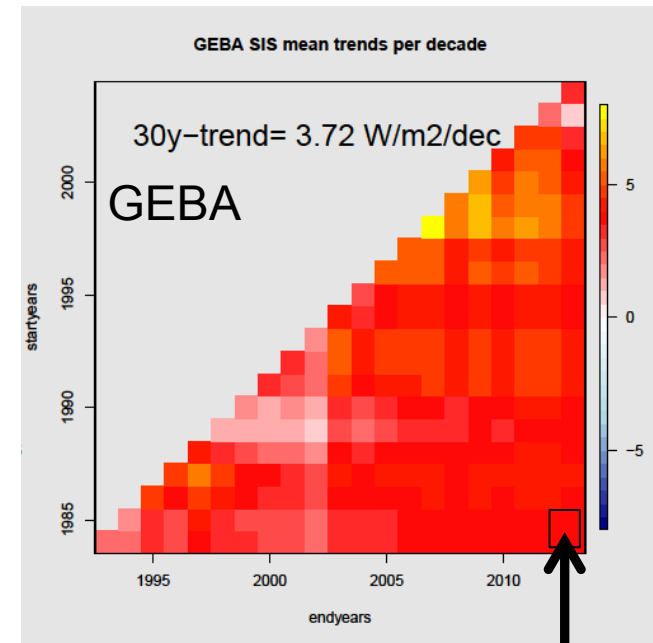
Trend in the US (1992 to 2015)

CLARA



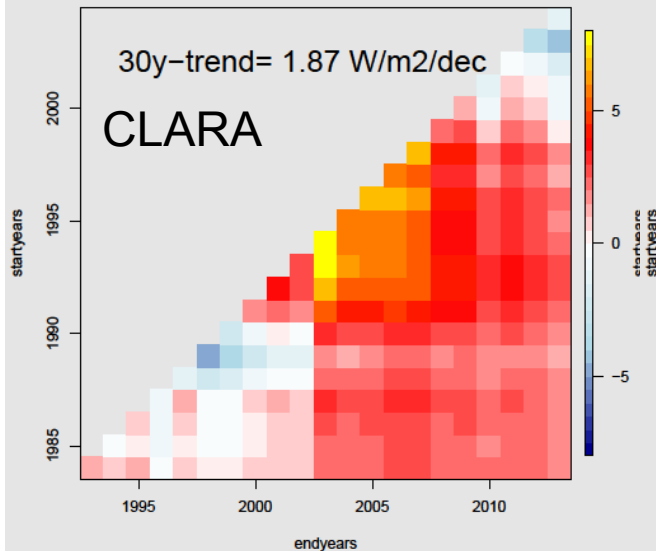
- Strong positive trend of surface irradiance in the CLARA data record with substantial spatial variability

Trend- and Variability-Analysis

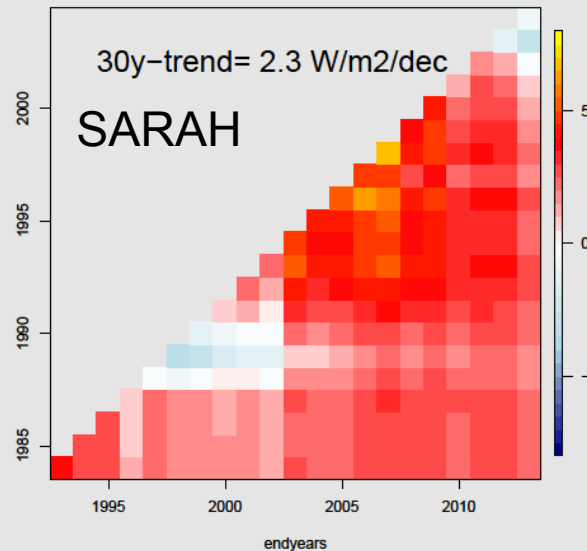


Trend- and Variability-Analysis

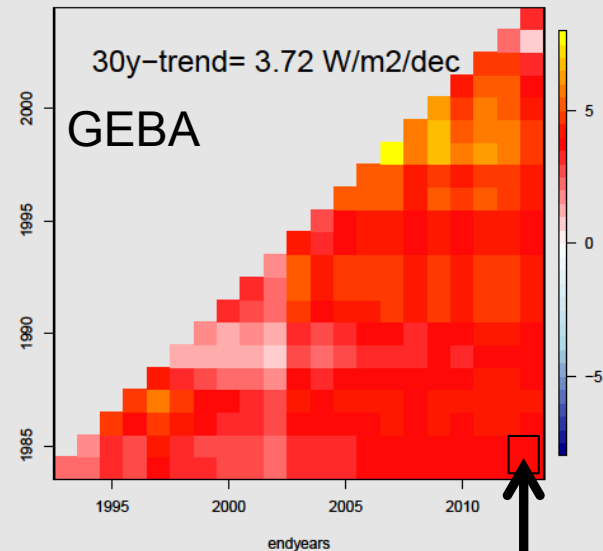
CLARA SIS mean trends per decade



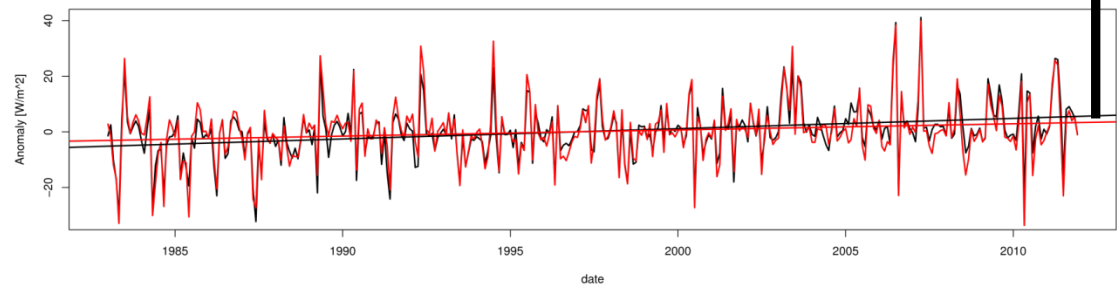
SARAH-2 SIS mean trends per decade



GEBA SIS mean trends per decade



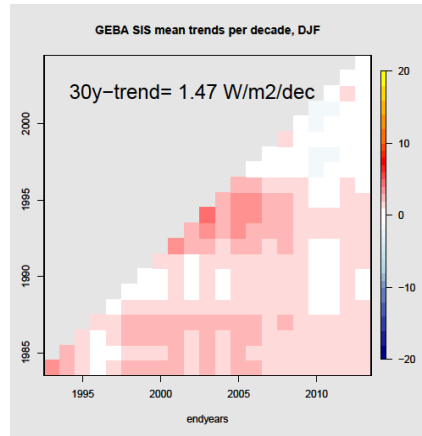
Anomaly Time Series, SARAH (red), GEBA (black)



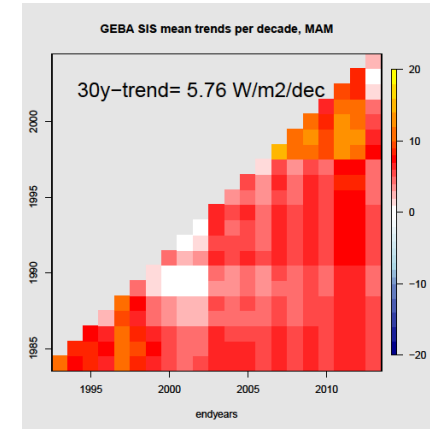
- Substantial temporal variability in decadal trends
- Moderate agreement of satellite- and surface-based estimates
- Satellite tends to underestimate

Trend- and Variability-Analysis: Seasonal

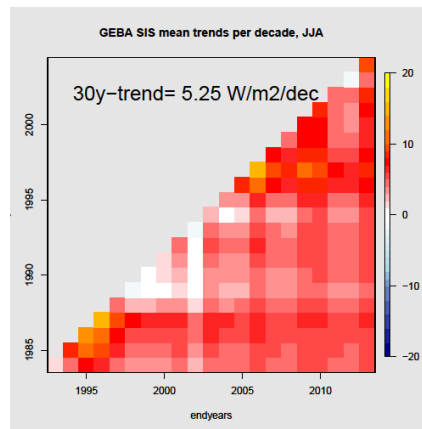
Winter



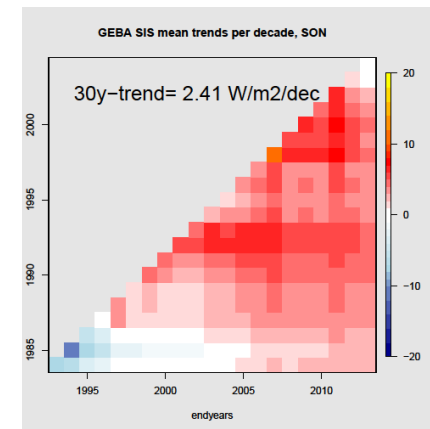
Spring



Summer



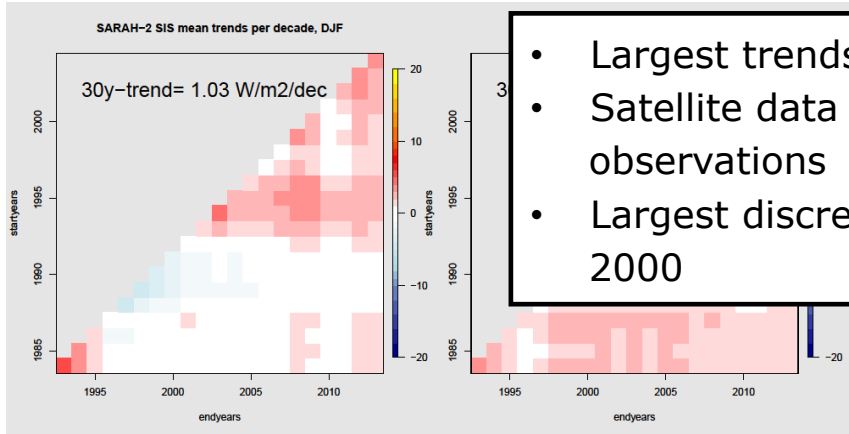
Autumn



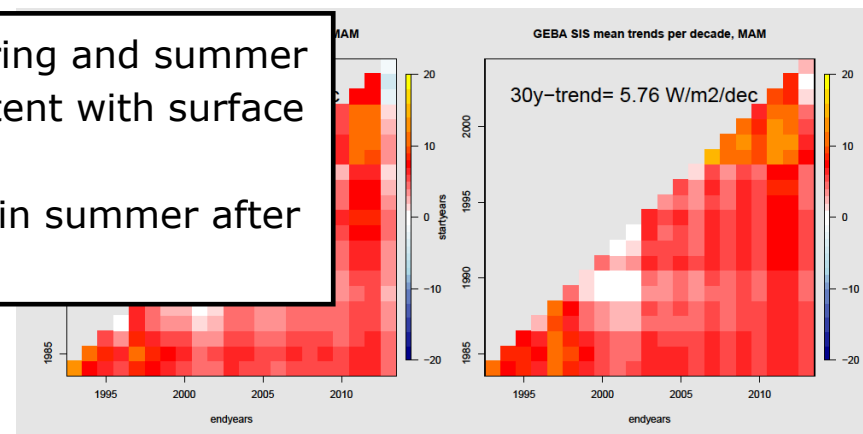
Trend- and Variability-Analysis: Seasonal

Winter

Spring

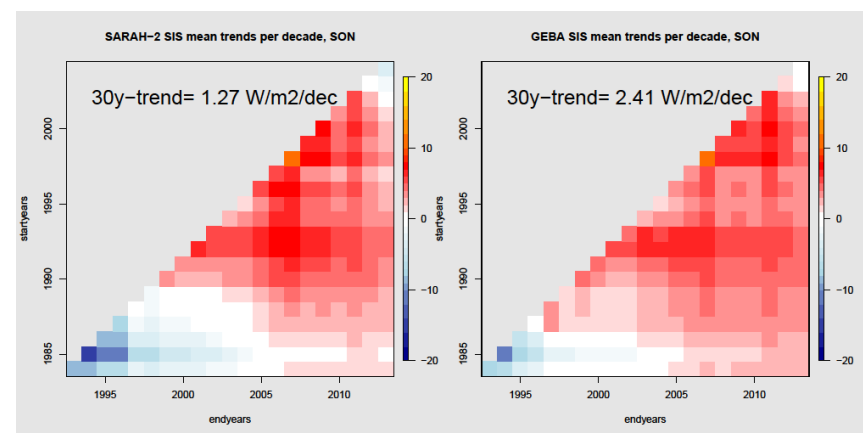
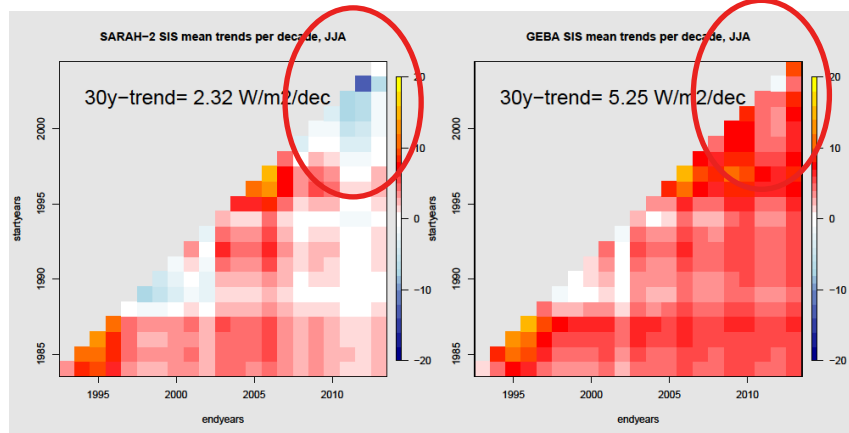


- Largest trends in spring and summer
- Satellite data consistent with surface observations
- Largest discrepancy in summer after 2000



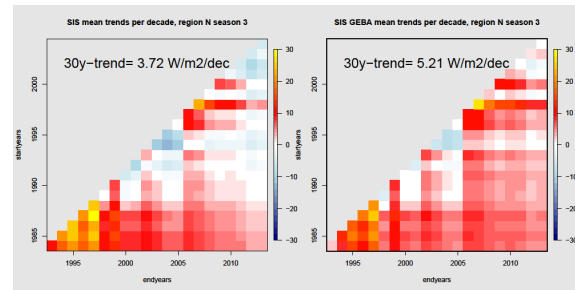
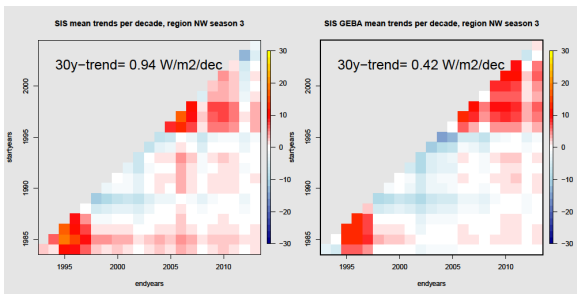
Summer

Autumn

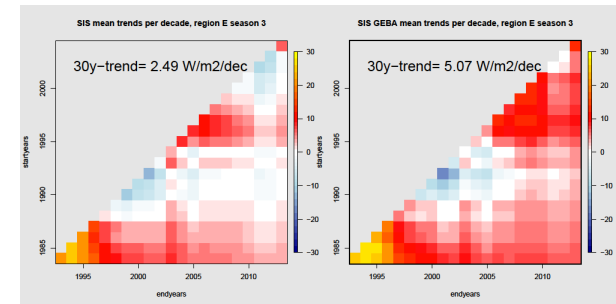


Trend- and Variability-Analysis: Summer, Regional North

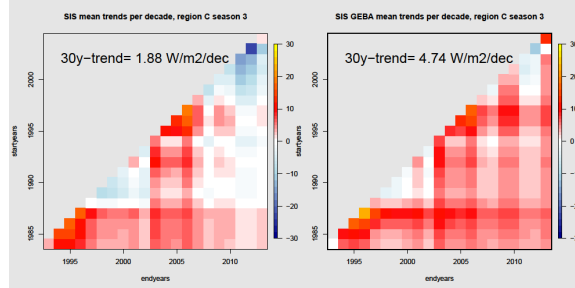
North-West



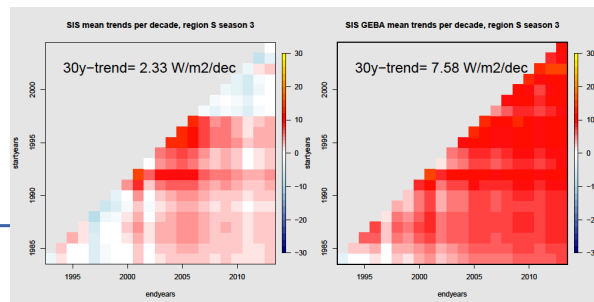
East



Central



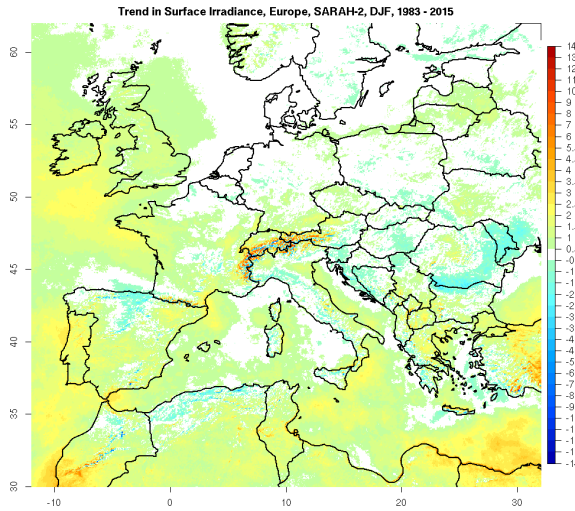
South



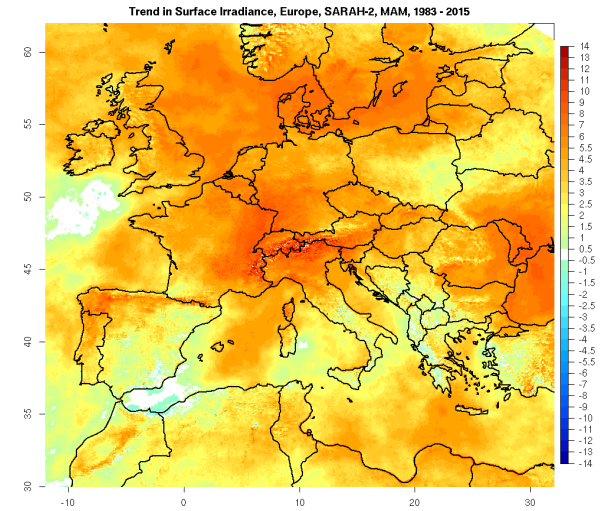
- Decent agreement in summertime variability in Northern Europe
- Increased under-estimation of trend in Eastern / Central / Southern Europe (after 2000)

Trend- and Variability-Analysis: Seasonal

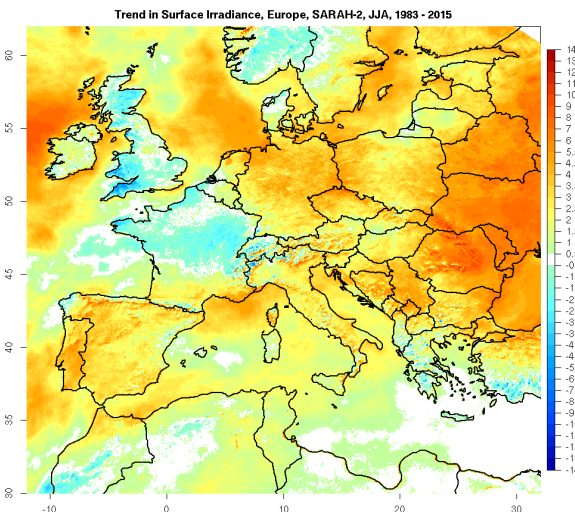
Winter



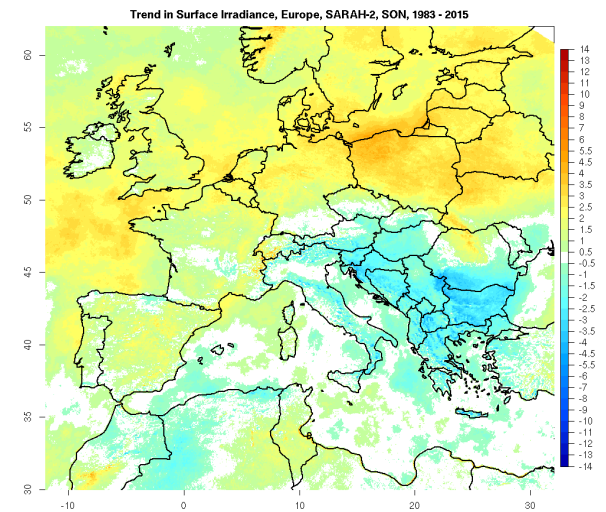
Spring



Summer

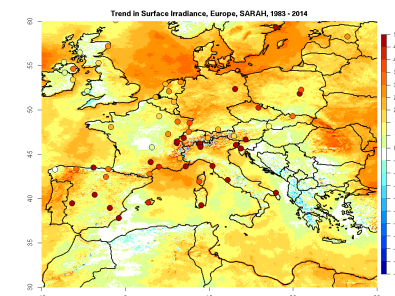
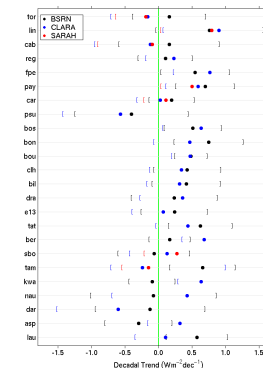
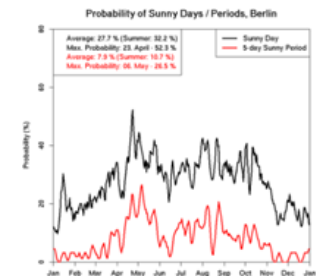
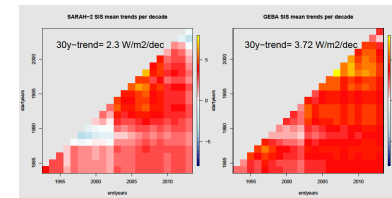
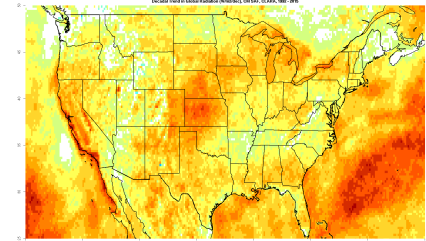
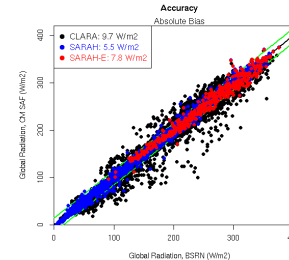


Autumn



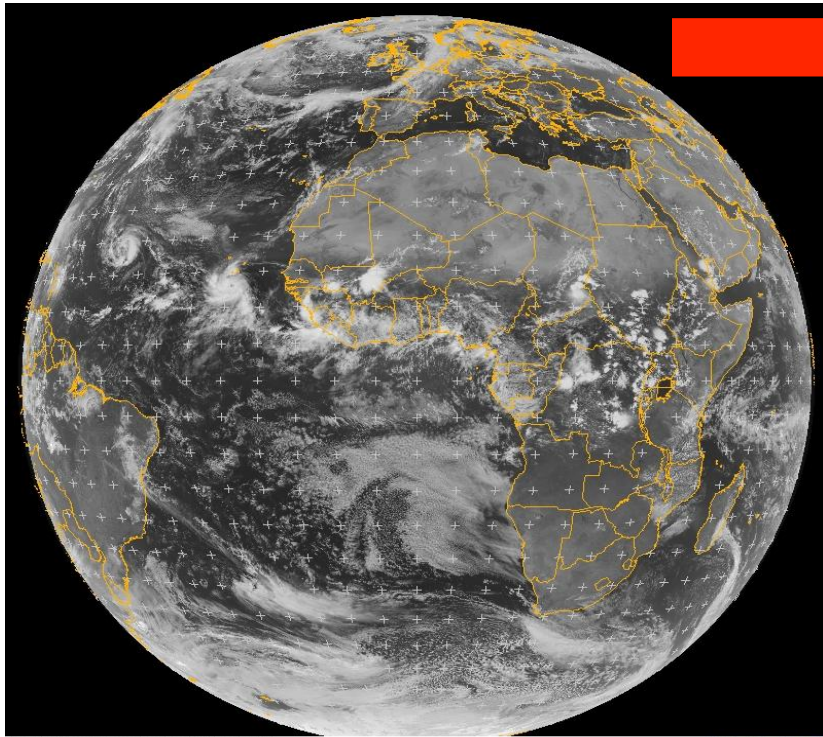
Summary

- ➔ The CM SAF Surface Solar Radiation data sets (SARAH(-E), CLARA) provide high quality information on the surface solar radiation.
- ➔ CM SAF Data Records reproduce the overall temporal trend and spatial variability (in Europe)
- ➔ Go to Berlin in May!
- ➔ Underestimation of the brightening by the satellite data records in Central / Southern Europe after 2000.



Extra Slides

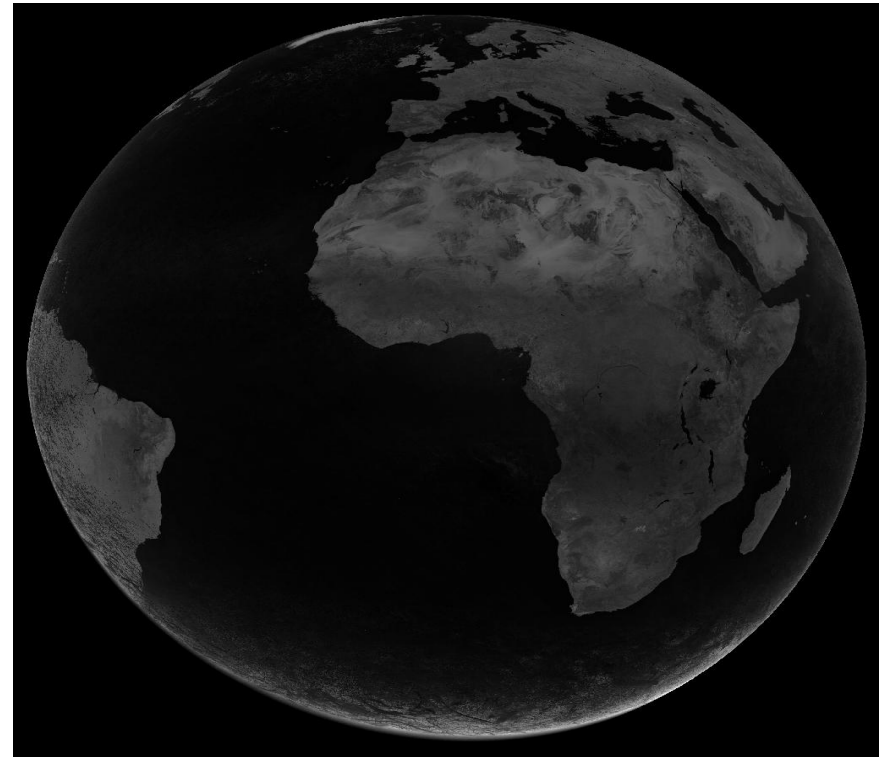
Reflectivity, 12 UTC, 2 Sept 2008



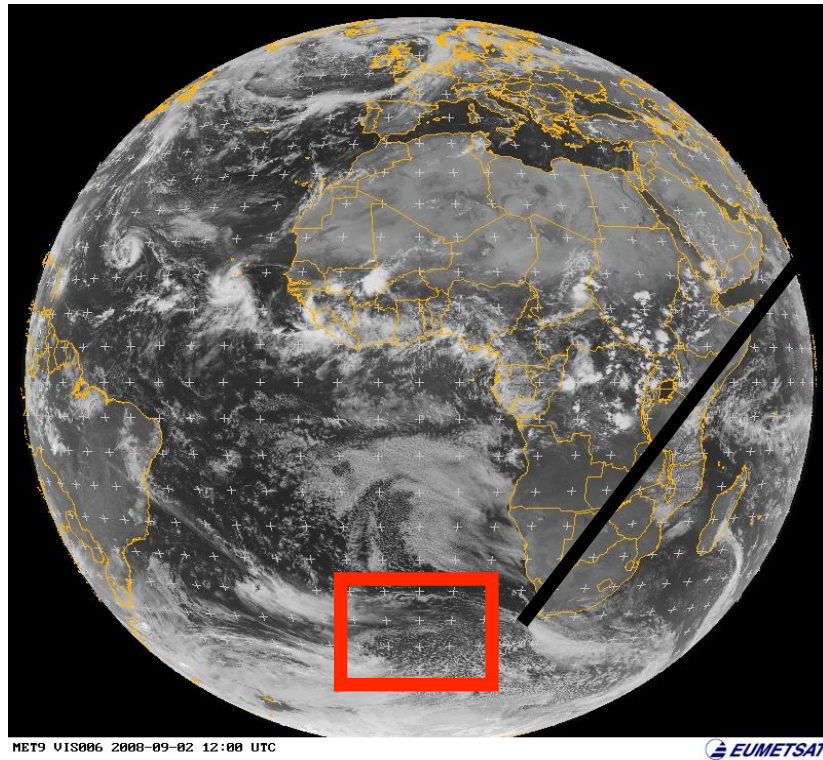
MET9 VIS006 2008-09-02 12:00 UTC

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Min. Reflectivity, R_{\min} , 12 UTC, **Sept 2008**

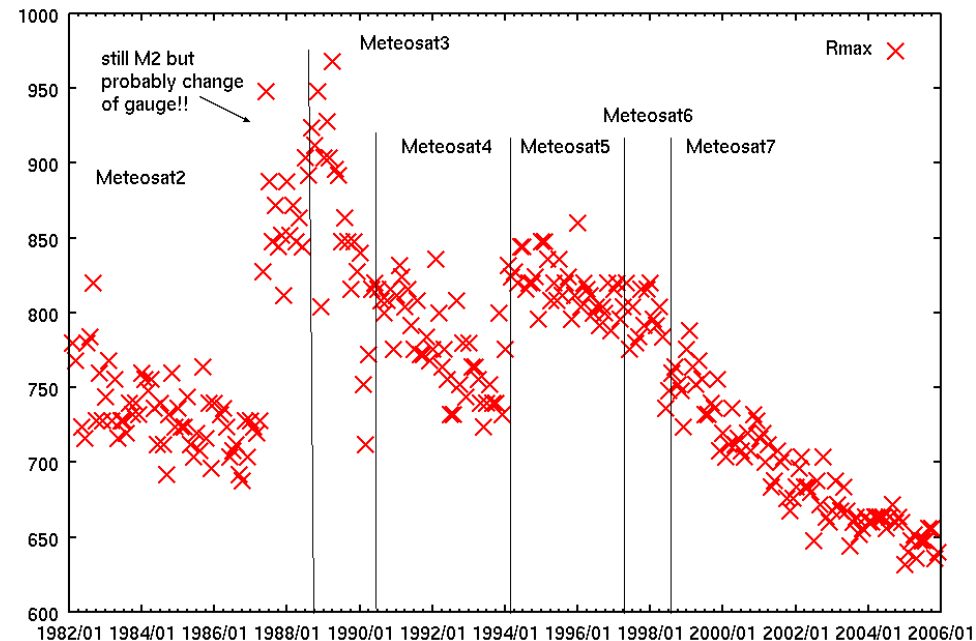


Reflectivity, 12 UTC, 2 Sept 2008



Max. reflectance, R_{\max} :
95 % percentile of counts
during one month in the
reference region

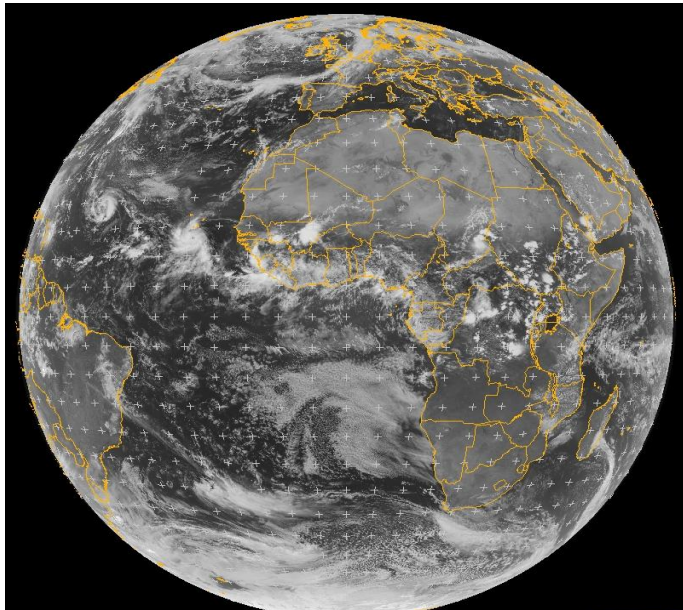
Temporal evolution of R_{\max}



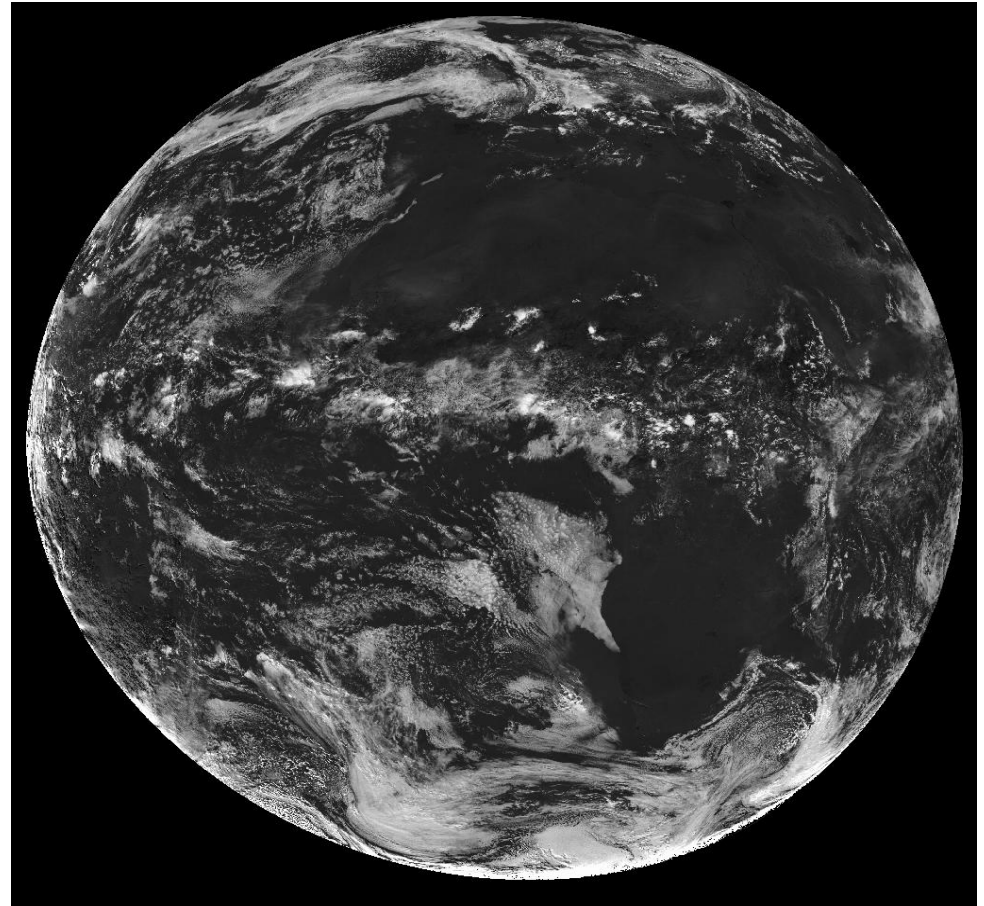
The definition of the Cloud Index n :

$$n = \frac{R - R_{min}}{R_{max} - R_{min}}$$

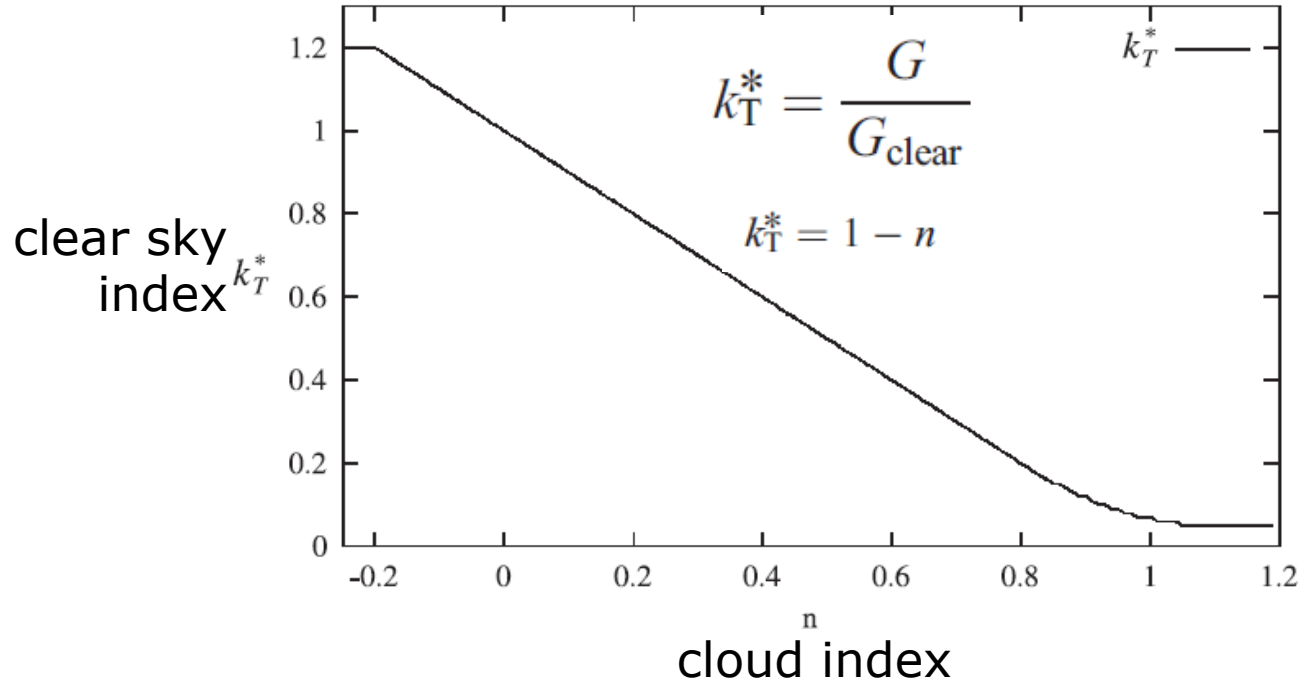
Cloud Index, 11 UTC, 1 July 2005



 EUMETSAT



- The cloud index, n , is related to the clear-sky index, k .
- The clear-sky index, k , is the ratio between the all-sky surface irradiance, G , and the clear-sky surface irradiance, G_{clear}



- The cloud index, n , is related to the clear-sky index, k :

$$k = 1 - n$$

- The clear-sky index, k , is the ratio between the all-sky surface irradiance, G , and the clear-sky surface irradiance, G_{clear} :

$$G = k * G_{\text{clear}}$$

- G_{clear} can be calculated by radiation transfer calculations using the fast and accurate clear-sky model **gnu-MAGIC** (*Mesoscale Atmospheric Global Irradiance Code*, Mueller et al., 2009, <http://sourceforge.net/projects/gnu-magic/>)